PROCEEDINGS OF SCIENCE

# The First Generation of Super-Massive Black Holes and Cosmic Backgrounds

**Peter L. Biermann**∗†
*Max Planck Institute for Radioastronomy, Bonn, Germany*
*E-mail:* plbiermann@mpifr-bonn.mpg.de

We observe i) a high energy neutrino background (Aartsen et al., IceCube Coll., 2013, 2014 and 2015), and there are repeated claims of a radio background (Fixsen et al., Kogut et al., Seiffert et al. 2011, Condon et al. 2012), ii) a large number of super-massive black holes, with a low mass cut-off in their distribution around $3 \cdot 10^6\ M_\odot$ (Caramete & Biermann 2010), and iii) a large number of massive disk galaxies that never merged (Kormendy et al. 2010, 2011a, b). The density of low mass galaxies also approaches a density consistent with the inferred density of these black holes (Conselice 2011, 2013). We propose that a first generation of super-massive black holes forms by the agglomeration of massive stars inside a small galaxy (Spitzer 1969, Sanders 1970); the ensuing super-massive star blows up around $10^6\ M_\odot$ due to an instability (Appenzeller & Fricke 1972a, b), and forms a black hole. The explosion then produces a hyper-nova remnant, which gives rise to a background in radio emission, $\gamma$ emission, neutrino emission, matching the observations. This explosion distributes fairly strong magnetic fields. The explosion also produces a massive gaseous shell, allowing the formation of massive disk galaxies. There has to be an ensuing background in polarized radio emission, as well as gravitational waves. This simple concept pulls together a large body of observational evidence, and allows predictions for future observational tests to be made.

*XI Multifrequency Behavior of High Energy Cosmic Sources Workshop*
*25-30 May 2015*
*Palermo, Italy*

∗Speaker.

†L.I. Caramete, B.C. Harms, E. Haug, A. Meli, I.F. Mirabel, B. B. Nath, V. de Souza, T. Stanev, and J.B. Tjus have contributed to this work significantly. A paper with some of these results was published in 2014, Biermann et al.





PoS(MULTIF15)008

## 1. The microwave background and its ripples

The microwave background ripples have been very well studied by the Planck satellite (Ade et al., Planck-Coll., 2015). A six-parameter model not only gives an excellent fit to the direct temperature power spectrum, but also to the independent polarization data, a very powerful test. An observed polarized background at moderately large wave-number (Ade et al., Bicep2 Coll., 2014) could be partially due to gravitational waves left from inflation, but is more likely to be due to Galactic dust (Ade et al., BICEP2/Keck and Planck Coll., 2015). The data only pertain to long length scales and so do not distinguish between various models for dark matter, such as Cold Dark Matter (CDM), or Warm Dark Matter (WDM) with a candidate DM Fermion particle on the keV scale. Including Dark Energy (DE), these models are referred to as ΛCDM or ΛWDM.

The 2015 numbers for the parameters (Ade et al., Planck-Coll., 2015) show: Dark energy $\Omega_\Lambda = 0.6911 \pm 0.0062$, dark matter $\Omega_{dm} = 0.2603 \pm 0.0062$, baryonic matter $\Omega_b = 0.04860 \pm 0.00031$, and so finally $\Omega_k = 1 - \Omega_\Lambda - \Omega_{dm} - \Omega_b = +0.0008 \pm 0.0040$. These results imply a “flat" geometry, like a perfect tabletop. The expansion scale of the universe is today $H_0 = 67.74 \pm 0.46\,\mathrm{km/s/Mpc}$. Assuming gradual step-wise re-ionization (Kogut et al. 2003): $z_{re-ion,init} \gtrsim 20$. Thomson depth: $\tau_T = 0.066 \pm 0.012$. The age of the universe: $t_0 = (13.799 \pm 0.021) \cdot 10^9\,\mathrm{yr}$. A comparison with the 2013 numbers demonstrates that we are converging (Ade et al., Planck-Coll., 2013).

With some trouble we can identify where the baryons are. We have no idea what dark energy and dark matter is. What and where is all this ?

## 2. Known backgrounds: Galaxies and Active Galactic Nuclei (AGN)

Galaxies and starburst galaxies (= galaxies with a temporary burst of star formation) show a correlation between the Far-Infra-Red (FIR), the radio and X-ray emission (Chini et al. 1989, Tabatabaei et al. 2010, 2012, 2013; for reviews see Condon 1992; and Kennicutt 1998). In general terms this is to be expected, since all three phenomena are caused by the massive stars (e.g., Biermann & Fricke 1977, Bieging et al. 1977, Kronberg & Biermann 1981). However, the quantitative details elude us, despite many attempts to solve this riddle (e.g., Völk 1989 and later papers).

All normal activity per comoving volume in the universe rises rapidly towards a redshift range between 1 and 2 (e.g., Lagache et al. 2005, Dole et al. 2006, Raue et al. 2009, Kneiske & Dole 2010, Duncan et al. 2014). This is true both for active star-forming galaxies, such as the starburst galaxy M82 (Kronberg et al. 1985), as well as Active Galactic Nuclei (AGN), such as the radio galaxy M87. So the maximum contribution to the background integral is expected to be at moderate redshift.

On the other hand, the universe is not uniform on those scales that we can easily observe, and so local effects cannot be readily discounted, except by careful observation. And yet, some categories of activity defy such simple rules, as for instance stellar black holes get more important at low metal abundance or high redshift (Mirabel et al 2011). One may surmise that super-massive black holes similarly favor very high redshifts; after all, they must have been initially produced at some epoch (Caramete & Biermann 2010).



PoS(MULTIF15)008

Active Galactic Nuclei (AGN: Big Black Holes) show a dichotomy in such correlations, with the strongest variation due to radio emission: radio-loud and radio-weak quasars exist, with all data consistent with the hypothesis, that all nuclei have a relativistic jet, albeit often a very weak one in terms of radio emission (Nagar et al. 2000, 2001, 2002a, b, 2005, Falcke et al. 2000).

AGN sometimes show a combination of a starburst with an active nucleus, allowing Ultra High Energy (UHE) nuclei injection, Cosmic Rays (CRs); so UHECR nuclei. This is the most straight-forward way to obtain heavy nuclei at very high energy. In the single-kick approximation of Achterberg (Gallant & Achterberg 1999, Achterberg et al. 2001) the existing shape of the CR-spectrum (across the knee around about 2 PeV up to the ankle around about 3 EeV; GeV = $10^9$ eV, TeV = $10^{12}$ eV, PeV = $10^{15}$ eV, and EeV = $10^{18}$ eV) is preserved, but shifted up by the Lorentz-factor of a relativistic shock squared. All subsequent transits of a charged particle scattering back and forth across the shock (see, e.g., Drury 1983) add only a modest factor each time.

All AGN seem to have a relativistic jet; if that jet is pointed at us, and is thus dominant in emission, huge selection effects occur, and sometime flat spectra are observed right from radio through the infrared (as for S5 1803+78); but they may show "inverse evolution". The flat spectrum is the sum of many self-absorbed components (Blandford & Königl 1979).

Selecting at 5 GHz, or 6 cm radio wavelength, half of all compact radio sources point at us (Gregorini et al. 1984).

Therefore we can expect also at least these broad classes in their corresponding radio/ FIR/ X-ray/ $\gamma$-ray/ UHECR/ gravitational wave (GW)/ neutrino emission.

To emphasize again: In all known source classes the maximum contribution is at moderate redshift as well - but there is much we do not know. Active stars and their directly observed activity cycles can teach us a lot.

All these ideas are testable via compact radio source counts, to the degree that the resulting sources are indeed compact.

## 3. UHE CR background

The cosmic ray spectrum above TeV shows the down-turn called the knee, around 2 PeV (protons) and the upturn called the ankle, around 3 EeV. In the Erice 2014 lecture Engel said, to quote: " around $10^{18}$ eV 60 - 80 % of events are extragalactic protons" (see Aab et al., Auger-Coll., 2014b). So we have the question: How many Supernovae contribute CRs near $10^{15}$ eV to $10^{16}$ eV, and yet allow the spectrum to show such a well-defined kink?

Gaisser, Stanev & Tilav (2013) show $< \ln A >$ vs energy; when comparing TA and Auger (Abbasi et al., Auger-Coll. and TA-Coll., 2015), consider the error bars, as within their respective error bars they are consistent. Examples: 1) 25 % each of H, C, O, Fe give $< \ln A >$ = 2.3, and 33 % of each C, O, Fe give 3.1, while pure H gives 0, and pure Fe gives 3.9. A new light component appears around 100 PeV, probably extragalactic.

Auger now shows the arrival directions of many events (e.g. Kotera, & Olinto 2011, Aab et al., Auger-Coll., 2015b). In most of such graphs today the Galactic Center (GC) is at the center; in others it is at the edge. If these events are heavy nuclei, then they come from only rather small distances. There is a clustering around the general direction of the radio galaxy Cen A, predicted to be a plausible source already 1963 by Ginzburg & Syrovatskij, before a single UHECR event was even observed (later that year Linsley 1963). Including interactions of nuclei, not many survive from even the next powerful candidate radio galaxy, M87; in fact, there is no clustering observed around the next two radio galaxy candidates, M87 = Vir A and For A. On the other hand, the probably extragalactic proton component visible from about 100 PeV, may arise from all normal radio galaxies, limited only by magnetic fields (Das et al. 2008, Ryu et al. 2008, 2010).

## 4. Early backgrounds?

Just after recombination and all its ripples we expect:

The first stars (earlier in ΛWDM, if DM-decay induced cooling is taken into account, see Biermann & Kusenko 2006).

But what is DM? An illusion (e.g. Kroupa 2015), a manifestation of a different gravity (e.g. Milgrom 2014)? A heavy particle, so the relevant model would be: ΛCDM? Or a light particle, around keV, as suggested by dwarf spheroidal galaxies: ΛWDM? Note again, that on all scales accessible to Planck ΛCDM and ΛWDM models are identical.

At some high redshift we have the first supernovae and first stellar black holes (BHs): first heavy elements, heavy element mass fraction $Z$ still very small, first Cosmic Rays (CRs).

And at some point we will obtain the first super-massive stars, their hyper-novae remnants (HNRs), their super-massive black holes (SMBHs).

They all produce detectable backgrounds in

- Radio, far-infrared (FIR), X-rays,
- $\gamma$-rays; their best sources are the blazars, all flat-radio-spectrum sources, relativistic jets pointed at Earth. These photons have a horizon, interestingly directly connected to the FIR-background (Mannheim et al. 1996, Raue et al. 2009, Kneiske & Dole 2010, Abramowski et al., H.E.S.S.-Coll., 2013); right now the FIR background based on counts just allows the spectra of the highest redshift TeV blazars to be understood (Costamante 2013). If we were to find any sources at even higher redshift, we could have a problem. Some (e.g. Essey & Kusenko 2010, 2014, Essey et al. 2010, 2011a, 2011b) have argued that we have a serious difficulty already, which could be solved by UHE protons (energies of only EeV are required for this effect) going almost exactly straight; the process is secondary production of $\gamma$-photons by interaction of these protons with the extragalactic photon field. Protons at these energies going straight requires either very low values for the magnetic field, or an extremely structured magnetic field. Given the integrated energy density of magnetic fields obtained from self-consistent modeling (Ryu et al. 2008) and their match with other observations (Kronberg et al. 2007, 2008), such extreme structuring just might barely be possible, and could be caused by radio galaxies themselves.
- Ultra-High Energy Cosmic Rays: They certainly have a horizon, the GZK-turn-off. We observe a turn-off, but it has not been proven, that the observed turn-off is due to losses, or to the space limitation in the source (Gopal-Krishna et al. 2010, Biermann & de Souza 2012, Todero Peixeto et al. 2015); Auger (Aab et al., Auger-Coll., 20014a, b, 2015a, 2015b) suggests that the chemical composition at the highest energy is nuclei heavier than Helium.

- Neutrinos: Observing neutrinos at Earth at around PeV (Aartsen et al., IceCube-Coll., 2013, 2014, 2015) implies that at very high redshift their energies are correspondingly higher, and so there just might be interaction. Work by T. Stanev (priv. comm.) suggests that the horizon for PeV neutrinos is around redshift 18. So, if we observe neutrinos to clearly beyond PeV, then the sources must be at a smaller redshift than 18; if the spectrum were to cut off near PeV, then the sources might be at higher redshift. The current data are fully consistent with a power-law spectrum and do not require a cutoff.

- Gravitational waves are produced whenever compact objects jerk around, so probably in the formation of black holes, as well as in the merger of black holes. These gravitational waves are in addition to the inflation contribution!

## 5. A new radio background

Three papers (Fixsen et al., Kogut et al., and Seiffert et al. 2011) all show based on observations, that an isotropic cosmic radio background exists, with a relatively flat spectrum, corresponding to a particle spectrum about $E^{-2.2}$ to $E^{-2.3}$.

In the analysis all known foregrounds have been subtracted. The latest (Ade et al., Bicep2-Coll., 2014; Ade et al., POLARBEAR-Coll., 2014; Ade et al., Bicep2/Keck and Planck Coll., 2015) Planck results demonstrate that Galactic dust may very well account for all the excess polarization detected by the BICEP2 experiment (2014). After compensating for the expected dust, everything in the polarization data is as expected.

This background detected by Fixsen, Kogut, and Seiffert et al. (2011) can be compared with the known compact radio source counts: no known compact radio source population could explain it (Condon et al. 2012). This background is also so smooth, that it again defies all known compact radio sources (e.g. Holder 2014). This implies that the sources are extended, and probably overlapping.

## 6. Neutrino background

The high energy neutrino background has been detected (Aartsen et al., IceCube-Coll., 2013, 2014, 2015), with a spectrum of $E^{-2.5\pm0.09}$ (1 sigma), no certain cutoff, no significant anisotropy, and and no identified plausible sources.

The analogy with $\gamma$-ray astronomy and flat spectrum radio sources would directly suggest (e.g., Becker & Biermann 2009) , that all these sources are blazars - relativistic jets pointed at us; if so, then any first suggested source ought to be a compact radio source with a flat or inverted radio spectrum (see, e.g., Krauss et al. 2014). As shown already in Gregorini et al. (1984), the threshold of variability, compactness and relativistic motion is at about a spectrum of (in flux density $S_\nu$ as a function of frequency $\nu$) $\nu^{-0.5}$, while for all radio galaxies not pointed at Earth the average spectrum corresponds to $\nu^{-0.82\pm0.04}$ in flux density for the extended emission, corresponding to a particle spectrum of $E^{-2.64\pm0.08}$. Radio spectra as flat as $\nu^{-0.5}$ or flatter correspond to the superposition of variable compact components.

There are two types of events, shower like events with a pointing uncertainty of about 10 degrees (half width), and track-like events about one degree, in precision of directionality. So, the track-like events offer a chance to identify a source.

At low flux density at 5 GHz, the known source sky density of flat spectrum radio sources (all blazars) is high enough to place a source every degree, at some level of slightly below 100 mJy. In other words, given any position outside the Galactic plane, and a radius of search of about a degree, the chance is very high to actually find a candidate source identification, just by chance.

The neutrino spectrum may cut off around several PeV. But at the current stage of statistics such a cut-off could be invisible for the spectrum observed. A single power-law model with no cutoff is a very good fit to the data.

## 7. Super-Massive Black Holes (BHs)

Starting with the 2-micron survey of galaxies, using colors, Hubble-types, and other evidence to conservatively cut down the sample, and then the Bulge-SMBH mass correlation, calibrated for each Hubble type separately (keeping only early Hubble types) gives a sample of slightly less than 3,000 objects (Caramete & Biermann 2010), within 100 Mpc, a distance suggested by magnetic scattering (Das et al., 2008, Ryu et al., 2008, 2010). This allows to study the sky distribution, as well as the mass function. This shows that SMBHs may begin around $3 \cdot 10^6\,M_\odot$, with the lower mass compact sources all possibly nuclear star clusters.

Such a mass can be explained in the picture of Spitzer (Spitzer 1969, Sanders 1970) of massive stars merging by agglomeration to form a super-massive star. Super-massive stars then become unstable due to a combination of high radiation pressure and General Relativity near a mass of about a million Solar masses (Appenzeller & Fricke 1972a, b). However, this growth is impeded by powerful stellar winds (Lucy & Solomon 1970, Yungelson et al. 2008) for any significant level of heavy elements. Therefore, this growth by agglomeration is only viable in a near zero abundance of heavy elements $Z$ in mass fraction, so in the very early universe (Biermann et al. 2014). This underlines the finding by Mirabel et al. (2011) that black hole formation changes at low $Z$.

This picture is supported by the observation, that at lower allowed masses nuclear star clusters still prevail in the centers of galaxies. The Spitzer and Gaia satellite missions will shed further light on this.

A viable but speculative picture is then that SMBHs formed near such a mass of about $3 \cdot 10^6\,M_\odot$ mass, and grew by merging in the early universe. At the redshifts accessible to observation today, all this merging is essentially over already. The mathematical theory of merging has been around for about 100 years now (Smochulowski 1916). Building on Smochulowski's work the analytic merging theory developed by Silk & Takahashi (1979) allows a full interpretation of the SMBH mass function, using what they refer to as gravitational focussing limit. An intermediate stage could be that we observe several super-massive black holes in a proto-cluster, as has now been observed (Hennawi et al. 2015).

## 8. The first CRs: radio and neutrino background

Since in Spitzer's approach super-massive black holes form from super-massive stars and begin at near zero heavy elements, we approximate their formation as a single epoch in the early universe, scaled to redshift 20, writing the redshift as $(1+z) = (1+20)\, z_{1.3}$. An alternate way to grow the first generation of super-massive black holes could be to grow them from degenerate configurations (Munyaneza & Biermann 2005, 2006). The explosion concurrent with the SMBH formation leads to shell formation, with some fraction of the energy going into newly induced magnetic fields, $\eta_B$, here scaled to 0.1, so writing $0.1\, \eta_{B,-1}$; and another fraction of energy similarly going into energetic electrons, $0.1\, \eta_{CR,e,-1}$, also scaled to 0.1. The energy going into the explosion is $10^{57}\, E_{57}$ ergs, scaled to a very low efficiency relative to the rest mass energy of the SMBH formed in this model. Finally we need to scale to the original comoving density of SMBH, $N_{BH,0,0}$, here scaled to 1 Mpc$^{-3}$, on the high side of what the data allow, which have relatively large error bars, $10^{-1.2\pm0.4}$ Mpc$^{-3}$, with most systematics suggesting a higher density. Finally we work out the radio background at a frequency of GHz, so writing $10^9\, \nu_{9.0}$ Hz (see, e.g. Drury 1983 for a review of acceleration of charged particles). We adopt a spectrum for the particles suggested by an explosion into a pristine medium, devoid of prior magnetic fields (Biermann et al. 2014), of $E^{-2.2}$. Obviously a slightly steeper spectrum can also be envisaged.

With these scalings we obtain a radio background of

$$F_{rad} \;=\; 10^{-19.8}\, N_{BH,0,0}\, \eta_{B,-1}^{0.8}\, \eta_{CR,e,-1}^{+1}\, E_{57}^{1.3}\, z_{1.3}^{+0.8} \\ \nu_{9.0}^{-0.60}\, \mathrm{erg\,s^{-1} Hz^{-1} cm^{-2} sr^{-1}}\,.$$

This matches the data (Biermann et al. 2014). Concurrently a neutrino background is also produced by interaction between energetic protons and the medium, using an efficiency to produce energetic protons of 0.1, and writing $0.1\, \eta_{CR,p,-1}$. The integrated neutrino flux is then

$$F_{neutr} \;=\; 10^{-7.5}\, N_{BH,0,0}\, E_{57}\, \eta_{CR,p,-1}\, z_{1.3}^{0.8} \\ \mathrm{GeV\, cm^{-2}\, s^{-1}\, sr^{-1}}\,,$$

Again this matches the data within the uncertainties (Biermann et al. 2014). The newest data analysis of IceCube (Aartsen et al., IceCube-Coll., 2015) suggests a slightly steeper spectrum $E^{-2.5\pm0.09}$ (1 sigma). Obviously, a parallel $\gamma$-ray background is also produced, close to what is observed.

## 9. Neutrino background: Tests and Criticism

A first question is whether the scenario outlined could help solve some other problems:

A well-known result from infrared surveys is that most big galaxies never merged; this result had been anticipated by the large galaxy statistics of Kormendy et al. (2010, 2011a, b), and the work by Conselice (2011, 2013).

In the model proposed here the explosion produces a corresponding massive gaseous shell of a mass

$$M_{shell} \;=\; 10^{10.4}\, \mathrm{M}_\odot\, E_{57}^{3/5}\, z_{1.3}^{-3/5}$$

If such shells break up into a small number of objects, say three or four, then this could provide an explanation of massive galaxies formed early. It would entail, that at lower masses a power-law of fragments might describe the galaxy mass function, a trade-off between further break-up and merging at very high redshift, while at higher masses a turn-over and cut-off might prevail.

Another speculative benefit is that this process yields many extra ionizing photons early (Kollmeier et al. 2014).

One criticism of the redshift 20 used here is that the WMAP and Planck data suggest a re-ionization redshift of about 10, and not anything close to 20. However, as pointed out by Kogut et al. (2003), the number of this redshift depends on assuming a complete step-function in ionization, a highly unlikely situation; assuming, instead, a two-step model for re-ionization, already puts the higher redshift at around 20, as used here.

One criticism based on the existing simulations for the early universe is that they do not show the SMBH formation as early as suggested here. However, none of these simulations allow for the catastrophic cooling via induced formation of molecular Hydrogen (Biermann & Kusenko 2006). Very few of these simulations (e.g. Paduroiu et al. 2015) allow for the small scale cutoff in the original power spectrum of disturbances induced by a dark matter particle of keV mass as suggested by dwarf galaxy data (e.g., Hogan & Dalcanton 2000; Gilmore et al. 2007, 2008; Koposov et al. 2008; Strigari et al. 2008; Gentile et al. 2009; Donato et al. 2009; Destri et al. 2012; Salucci et al. 2012; de Vega et al. 2014; Yang et al. 2014; Abazajian 2014). If the recent claim of a possible detection of an X-ray line around 3.5 keV (Bulbul et al. 2014) is confirmed, arising from the decay of a sterile neutrino of 7 keV, then the calculations in Biermann & Kusenko (2006) show that extreme induced cooling is possible from redshift 100 (for 4 keV sterile neutrino this redshift would be 80).

One may ask, why such an extreme cooling is even relevant at an epoch, when no strong density fluctuations are present: Simulations show that the differential flow between baryonic matter and dark matter is already substantially super-sonic flow right after recombination (Tseliakhovich & Hirata 2010; O'Leary & McQuinn 2012; Visbal et al. 2012; Fialkov 2014); this then naturally leads to shock waves, and the question, whether we might have cooling shocks, so strongly amplifying the underlying weak density disturbances. Combining this with Biermann & Kusenko's (2006) argument this would suggest that from redshift about 100 this amplifying mechanism may be at work, allowing very large baryon density jumps in such shocks.

## 10. Neutrino background: Alternatives

Could starburst and normal galaxies may give the observed neutrino background? CR-interactions using Galactic CRs give spectral kink down at $\sim$ 100 TeV, spectrum below $E^{-2}$ to $E^{-2.3}$: So, normal galaxies and starburst galaxies can only explain the observed neutrino spectrum, if the cosmic ray knee feature, the turn-down around 2 PeV (for protons) is at very much higher energy in many galaxies.

One test could be: Compare our own Galaxy, at lower $Z$ the small galaxy M33, and at starburst galaxies such as M82, using stacking with data of similar galaxies to see, whether the knee could be at higher energy.



PoS(MULTIF15)008

Seyfert galaxies and quasars interact strongly near their central SMBH; their maximum particle energy is limited by losses, such that the resulting maximal neutrino energy is somewhat lower than PeV (Nellen et al. 1993); all normal activity in the universe, such as starbursts and AGN, peak around redshift 1 to 2, and so this implies that in the sources the spectrum must be reaching ankle-like energies (for protons) with a straight spectrum. A test for such an hypothesis could be to stack the neutrino data for all prominent Seyfert galaxies.

Radio galaxies are relativistic jets oriented elsewhere: Combined with starburst they are best bet for UHE nuclei, but this is only a small fraction of all radio galaxies. Normal radio galaxies probably show mostly protons, possibly identified at energies below 10 EeV, as a rising component. The main challenge in assuming radio galaxies to be the main source is, however, to explain that the model suggested in Becker & Biermann (2009) discussed proton-gamma interaction as the main interaction candidate. Here, a break in the spectrum should be present; this must be outside the detected energy range. An alternative is proton-proton interaction as discussed in Becker et al. (2014); the details of these models are currently being investigated. If this is the correct interpretation for the high energy proton component, then another test would be the spectrum. A test for such a hypothesis could again be a stacking of all neutrino data for radio galaxies such as M87, For A, Cen A, and the like.

The relativistic sources aimed at us could be expected to show the strongest effect, just as they do in $\gamma$-rays: Blazars are relativistic jets pointed at us! Most correspond to low power radio galaxies, with the maximum particle energy constrained. So low flux density flat spectrum radio sources are the best candidates under this hypothesis. For this the best test is to look at 3C279, and many similar sources, again using stacking of the neutrino data. If radio galaxies are indeed the sources of the ultra high energy cosmic rays, then the neutrino spectrum ought to get close to $10^{19}$ eV, from those radio galaxies pointed at us.

The interactions in the IGM (= Intergalactic Galactic Medium) might also become important, following Essey & Kusenko (2010, 2014) and Essey et al. (2010, 2011a, 2011b) who argue that the intergalactic magnetic fields are so weak as to allow straight-line propagation of high energy protons. If this is important, then the connection between sources distance and neutrinos detected might be quite different, as in such a picture neutrinos are also produced en route. And again, blazars might be used to test this, as then both the $\gamma$-spectrum, and the neutrino spectrum have to match simultaneously.

Finally, how would we test the picture presented here, using the formation of the first generation of SMBHs?

The main test is the confirmation of the very high redshift, at which this might happen, and so its connection to very low heavy element abundance. The best determination of redshift is via absorption lines of the molecule HD in its neutral or ionized form (Galla & Palli 2013). In the early universe lines of HD are better relative to $H_2$ than in the normal Inter-Stellar Medium (ISM). Since the sources overlap, we can expect along any line of sight a forest of such lines, possibly in absorption against the light of the first super-massive stars. Typical wavelengths are around 100 nm, so in the redshift range 20 to 100 this corresponds to a wave-length of 2 to 10 $\mu$m, very difficult.

Another viable alternative is the manifestation of the earliest stellar BHs following (Mirabel et al. 2011); due to the constraint of extended sources, so as not to violate the compact source count



PoS(MULTIF15)008

limit (Condon et al. 2012, Holder 2014) we adopt the point of view here, that many local bursts of star formation produce this radio emission:

The observed (Simpson et al. 2015) median star formation rate in the 23 submm-galaxies (SMGs) sample is $SFR = 1170 \pm 160 M_{\odot} yr^{-1}$ (for a Salpeter IMF); the derived median star formation density is $90 \pm 30 M_{\odot}\, yr^{-1}\, kpc^{-2}$, and the typical size of a starburst region is a few kpc. We note that the Eddington limit for radiation pressure regulated starbursts is $\sim 1000 M_{\odot}\, yr^{-1}\, kpc^{-2}$ (Andrews & Thompson 2011).

We use then $10^{-2}\,\mathrm{Mpc}^{-3}\, N_{gal,0,-2}$ for our galaxy density, scaled to today; $10 N_{bursts,1}$, for the number of outbursts per galaxy; $100\, f_{dens.,2}$ for the density enhancement in the galaxy environment over the average cosmological density; and $10^{56}\, E_{56}$ ergs, as the energy per outburst: this is the same energy estimated as for other extreme outflows (Su et al. 2010). We dub this the "Fermi-bubble model" and so obtain for the integral neutrino flux

$$F_{neutr} = \sum 10^{-7.5}\, N_{gal,0,-2}\, N_{bursts,1}\, E_{56}\, f_{dens.,2}\, z_{1.3}^{0.8}\, \eta_{CR,p,-1}\, \mathrm{GeV\, cm^{-2}\, s^{-1}\, sr^{-1}}\,,$$

So again, this model easily explains the observations. However, in this approach the epoch of activity is an entire range of redshifts, all at very low metal abundance $Z$. Since in this case the environment is not pristine with respect to magnetic fields, the expected spectrum is steeper, more like $E^{-2.42 \pm 0.04}$ (Biermann & Strom 1993). However, we note again that here the observations require the source particle energies to reach near EeV energies.

## 11. Odd coincidence

There is an odd coincidence in numbers, noted in discussions with B. Harms: What is the energy maximally ejected when making a black hole? This limit is about (1/2) the rest mass energy for spin zero BH for the merging of equal mass BHs (Hawking 1971). We adopt this number as reference.

Then the energy budget scaled to the epoch of SMBH formation is

$$\frac{1}{2} N_{BH,0}\, M_{BH}\, c^2 (1 + z_{\star})^3$$

For $N_{BH,0} = 1 Mpc^{-3}$, $M_{BH} = 3 \cdot 10^6 M_{\odot}$, and $z_{\star} = 50$ the resulting energy density is $\sim 10^{-8}\, erg/cc$, which is the same as dark energy (DE; Frieman et al. 2008).

Is dark energy in this model just gravitational waves (Biermann & Harms 2014)?

We need to emphasize that the uncertainties in $N_{BH,0}$, $M_{BH}$, and also $z_{\star}$ are very large: The original SMBH density could be lower by an order of magnitude; the mass of these original SMBG could be anywhere between $10^6$ and $10^7\,\mathrm{M}_{\odot}$, and the redshift of formation could be anywhere between redshift 20 and 100. All this together results in an uncertainty of about four orders of magnitude.

But how could such an original energy density be maintained? In a five-dimensional world model energy transfer from a strong brane to a weak brane (us) can mimic the E.O.S. $P = -\rho\, c^2$!.

Harms (priv.comm.) has solved the Einstein and conservation equations analytically that describe such an energy transfer.

Following this speculative line of thought an obvious question is, how could we test this observationally? In the case, that gravitational waves then describe dark energy, this energy ought to be detectable with the Gaia mission (e.g. Klioner 2014) as well as with pulsar timing, as a Planck-like spectrum of gravitational waves corresponding to the original SMBH mass, redshifted.

This speculative prediction will be tested with Gaia within the next few years.

## 12. CONCLUSIONS: The early universe is visible !

- The radio, FIR, X-rays, and $\gamma$-ray backgrounds can be partially traced to the earliest manifestation so stellar BH and SMBH formation.
- Similarly the UHECRs, and high energy neutrinos will shed light on the activity of SMBH, possibly on the earliest generation of these. We test the processes with UHECRs, and then use the best model to predict the universal neutrino background.
- The gravitational wave background, whenever and at whatever level it will be detected, surely relates to the formation and merging of black holes. This background might even be detectable (Mignard & Klioner 2012, Klioner 2014, Taylor et al. 2015), if it is diluted by cosmic expansion (i.e. by $(1+z)^4$ from formation to now).
- To which background do the early stellar BHs contribute the most?
- To which background do the early SMBHs contribute the most, the neutrinos, the excess non-thermal radio emission, and gravitational waves?
- Do the massive gaseous shells around freshly formed SMBH explain the formation of massive disk galaxies?
- Can the high energy $\gamma$-emission of blazars be reconciled with the observed FIR-background from young starburst galaxies and normal galaxies? Or do we require straight-line propagation of very high energy protons?
- What do all these backgrounds require of cosmic magnetic fields and their structure? Is the structure extremely inhomogeneous so as to allow straight-line propagation and at the same time obey the integral energy input constraints?
- Test I: Identify the HE neutrino sources.
- Test II: Get redshifts from HD and $HD^+$ absorption lines against the light of the first stars, the first super-massive stars, and the exploding stars.
- Test III: Detect the original explosion, leading to the first generation of SMBHs. This ought to be a primary goal.
- Test IV: Detect the gravitational wave background due to the formation and initial merging of the first generation of SMBHs.



PoS(MULTIF15)008

## Acknowledgments

The author wishes to thank J. Black, R. Buta, R. Clay, Ch. Conselice, L. Costamante, C. Dobrigkeit Chinellato, R. Engel, A. Fialkov, G. Gilmore, W. Keel, A. Kogut, J. Kormendy, N. Sanchez, G. Smoot, C.J. Todero Peixoto, H. de Vega, and C. Watson for many discussions of these topics.

## References

[1] Aab, A., et al., Auger-Coll., *Phys. Rev.* **D 90**, 122005 (2014a); Title: Depth of Maximum of Air-Shower Profiles at the Auger Observatory: Measurements at Energies above $10^{17.8}$ eV

[2] Aab, A., et al., Auger-Coll., *Phys. Rev.* **D 90**, 122006 (2014b); Title: Depths of Maximum of Air-Shower Profiles at the Pierre Auger Observatory: Composition Implications

[3] Aab, A., et al., Auger-Coll., *Astrophys. J.* **802**, 111 (2015a); Title: Large scale distribution of ultra high energy cosmic rays detected

[4] Aab, A., et al., Auger-Coll., *Astrophys. J.* **804**, 15 (2015b); Title: Searches for Anisotropies in the Arrival Directions of the Highest Energy Cosmic Rays Detected by the Pierre Auger Observatory

[5] Aartsen, M.G., et al., IceCube-Coll., *Science* **342**, 1242856 (2013); astro-ph/1311.5238; Title: Evidence for High-Energy Extraterrestrial Neutrinos at the IceCube Detector

[6] Aartsen, M.G., et al., IceCube-Coll., *Phys. Rev. Letters* **113**, 101101 (2014); astro-ph/1405.5303; Title: Observation of High-Energy Astrophysical Neutrinos in Three Years of IceCube Data

[7] Aartsen, M.G. , et al., IceCube Coll., *Astrophys. J.* **809**, 98 (2015); arXiv/1507.03991; Title: A combined maximum-likelihood analysis of the high energy astrophysical neutrino flux measured with IceCube

[8] Abazajian, K.N., *Phys. Rev. Letters* **112**, 161303 (2014); Title: Resonantly Produced 7 keV Sterile Neutrino Dark Matter Models and the Properties of Milky Way Satellites

[9] Abbasi, R., et al., IceCube-Coll., *Nature* **484**, 351 (2012); Title: An absence of neutrinos associated with cosmic-ray acceleration in gamma-ray bursts

[10] Abbasi, R.U., et al., TA-Coll., *Astrophys. J. Letters* **790**, L21 (2014); Title: Indications of Intermediate-scale Anisotropy of Cosmic Rays with Energy Greater Than 57 EeV in the Northern Sky Measured with the Surface Detector of the Telescope Array Experiment

[11] Abbasi, R., et al., Auger-Coll., and TA-Coll., eprint 1503.07540 (2015); Title: Report of the Working Group on the Composition of Ultra High Energy Cosmic Rays

[12] Abramowski, A., et al., H.E.S.S. Coll., *Astron. & Astroph.* **550**, A4 (2013); Title: Measurement of the extragalactic background light imprint on the spectra of the brightest blazars observed with H.E.S.S.

[13] Achterberg, A., et al., *Month. Not. Roy. Astr. Soc.* **328**, 393 - 408 (2001); Title: Particle acceleration by ultra-relativistic shocks: theory and simulations

[14] Ade, P.A.R., et al., Planck Coll.; Astron. & Astroph. **571**, id.A16, (2014); arXiv:1303.5076; Title: Planck 2013 results. XVI. Cosmological parameters

[15] Ade, P.A.R., et al., Bicep2 Coll., *Phys. Rev. Letters* **112**, id.241101 (2014); arXiv:1403.3985; Title: Detection of B-Mode Polarization at Degree Angular Scales by BICEP2

[16] Ade, P.A.R., et al., Polarbear Coll., *Phys. Rev. Letters* **113**, id.021301 (2014); Title: Measurement of the Cosmic Microwave Background Polarization Lensing Power Spectrum with the POLARBEAR Experiment

[17] Ade, P.A.R., et al., BICEP2/Keck and Planck Coll., *Phys. Rev. Letters* **114**, 101301 (2015); Title: Joint Analysis of BICEP2/Keck Array and Planck Data

[18] Ade, P.A.R., et al., Planck Coll., eprint arXiv:1502.01589 (2015); Title: Planck 2015 results. XIII. Cosmological parameters

[19] Andrews, B.H., & Thompson, T.A., *Astrophys. J.* **727**, 97 (2011); Title: Assessing Radiation Pressure as a Feedback Mechanism in Star-forming Galaxies

[20] Appenzeller, I., & Fricke, K., *Astron. & Astroph.* **18**, 10 (1972a); Title: Hydrodynamic Model Calculations for Supermassive Stars I. The Collapse of a Nonrotating $0.75 \times 10^6 M_\odot$ Star

[21] Appenzeller, I., & Fricke, K., *Astron. & Astroph.* **21**, 285 (1972b); Title: Hydrodynamic Model Calculations for Supermassive Stars. II. The Collapse and Explosion of a Nonrotating $5.2 \times 10^5 M_\odot$ Star

[22] Becker, J.K., Biermann, P.L., *Astropart. Phys.* **31**, 138 - 148 (2009); Title: Neutrinos from active black holes, sources of ultra high energy cosmic rays

[23] Becker, J.K., & Biermann, P.L., *Astropart. Phys.* **31**, 138 (2009); Title: Neutrinos from active black holes, sources of ultra high energy cosmic rays

[24] Becker Tjus, J., et al., *Phys. Rev.* **D 89**, 123005 (2014); Title: High-energy neutrinos from radio galaxies

[25] Bieging, J.H., et al., *Astron. & Astroph.* **60**, 353 - 360 (1977); Title: Radio continuum observations of Markarian galaxies at 1410 MHz and 2700 MHz

[26] Biermann, P.L., & Fricke, K., *Astron. & Astroph.* **54**, 461 - 464 (1977); Title: On the origin of the radio and optical radiation from Markarian galaxies

[27] Biermann, P.L., & Strittmatter, P.A., *Astrophys. J.* **322**, 643 (1987); Title: Synchrotron emission from shock waves in active galactic nuclei

[28] Biermann, P.L., & Strom, R.G., *Astron. & Astroph.* **275**, 659 (1993), astro-ph/9303013; Title: Cosmic Rays III. The cosmic ray spectrum between 1 GeV and $10^4$ GeV and the radio emission from supernova remnants,

[29] Biermann, P.L., et al., *Astrophys. J. Letters* **604**, L29 - L32 (2004); Title: The Last Gamma-Ray Burst in Our Galaxy? On the Observed Cosmic-Ray Excess at Particle Energy $10^{18}$ eV

[30] Biermann, P.L., & Kusenko, A., *Phys. Rev. Letters* **96**, 091301 (2006); Title: Relic keV Sterile Neutrinos and Reionization

[31] Biermann, P.L., & de Souza, V., *Astrophys. J.* **746**, 72 (2012); arXiv: 1106.0625; Title: Centaurus A: the one extragalactic source of cosmic rays with energies above the knee

[32] Biermann, P.L., & Harms, B.C., *The Tenth Intern. Workshop on Multifrequ. Behav. of High Energy Cosmic Sources*, Palermo, Italy, 2013. *Acta Polyt. CTU Proc.* **1(1)**, 20 - 26 (2014); Title: Gravitational Waves and Dark Energy

[33] Biermann, P.L., et al., *Month. Not. Roy. Astr. Soc.* **441**, 1147 - 1156 (2014); arXiv:1403.3804; Title: Cosmic backgrounds due to the formation of the first generation of supermassive black holes,

[34] Blandford, R. D., & Königl, A., *Astrophys. J.* **232**, 34 - 48 (1979); Title: Relativistic jets as compact radio sources

[35] Bulbul, E., et al., *Astrophys. J.* **789**, 13 (2014); Title: Detection of an Unidentified Emission Line in the Stacked X-Ray Spectrum of Galaxy Clusters

[36] Bykov, A.M., et al., *Month. Not. Roy. Astr. Soc.* **453**, 113 (2015); arXiv:1507.04018; Title: Ultra-hard spectra of PeV neutrinos from supernovae in compact star clusters

[37] Caramete, L.I., & Biermann, P.L., *Astron. & Astroph.* **521**, A55 (2010); arXiv:0908.2764; Title: The mass function of nearby black hole candidates

[38] Chini, R., Kreysa, E., & Biermann, P.L., *Astron. & Astroph.* **219**, 87 - 97 (1989); Title: The nature of radio-quiet quasars

[39] Colafrancesco, S., et al., *Astron. & Astroph.* **566**, A42 (2014); Title: Multifrequency constraints on the non-thermal pressure in galaxy clusters

[40] Condon, J. J., *Annual Rev. of Astron. & Astrophys.* **30**, 575 - 611 (1992); Title: Radio emission from normal galaxies

[41] Condon, J.J., et al., *Astrophys. J.* **758**, 23 (2012); eprint arXiv:1207.2439 (2012); Title: Resolving the Radio Source Background: Deeper Understanding Through Confusion,

[42] Conselice, C.J., et al., *Month. Not. Roy. Astr. Soc.* **417**, 2770 - 2788 (2011); Title: The tumultuous formation of the Hubble sequence at $z > 1$ examined with HST/Wide-Field Camera-3 observations of the Hubble Ultra Deep Field

[43] Conselice, C.J., et al., *Month. Not. Roy. Astr. Soc.* **430**, 1051 - 1060 (2013); Title: Gas accretion as a dominant formation mode in massive galaxies from the GOODS NICMOS Survey

[44] Costamante, L., *Int. J. of Mod. Phys.* **D 22**, 1330025 (2013); Title: Gamma-Rays from Blazars and the Extragalactic Background Light

[45] Couderc, P., *Ann. d'Ap.* **2**, 271 (1939); Title: Les auréoles lumineuses des Novae

[46] Dalcanton, J.J., & Hogan, C.J., *Astrophys. J.* **561**, 35 (2001); Title: Halo Cores and Phase-Space Densities: Observational Constraints on Dark Matter Physics and Structure Formation

[47] Das, S., et al. *Astrophys. J.* **682**, 29 - 38 (2008); Title: Propagation of Ultra-High-Energy Protons through the Magnetized Cosmic Web

[48] Destri, C., de Vega, H.J., & Sanchez, N.G., eprint arXiv:1204.3090 (2012); Title: Fermionic warm dark matter produces galaxy cores in the observed scales

[49] Dole, H., Lagache, G., & Puget, J., *The Spitzer Space Telescope: New Views of the Cosmos*, . Eds. L. Armus & W.T. Reach. ASP Conf. Ser. **357**, 290 (2006); arXiv:astro-ph/0503017; Title: The Cosmic Infrared Background: Resolved, Unresolved and Spitzer Contribution

[50] Donato, F., et al., *Month. Not. Roy. Astr. Soc.* **397**, 1169 - 1176 (2009); Title: A constant dark matter halo surface density in galaxies

[51] Drury, L. O'C, *Rep. Progr. Phys.* **46**, 973 (1983); Title: An introduction to the theory of diffusive shock acceleration of energetic particles in tenuous plasmas

[52] Duncan, K., et al., *Month. Not. Roy. Astr. Soc.* **444**, 2960 - 2984 (2014); Title: The mass evolution of the first galaxies: stellar mass functions and star formation rates at $4 < z < 7$ in the CANDELS GOODS-South field

[53] Dwek, E., Arendt, R.G., *Astrophys. J.* **685**, 976 - 987 (2008); Title: Infrared Echoes Reveal the Shock Breakout of the Cas A Supernova

[54] Essey, W., & Kusenko, A., *Astropart. Phys.* **33**, 81 - 85 (2010); Title: A new interpretation of the gamma-ray observations of distant active galactic nuclei

[55] Essey, W., et al., *Phys. Rev. Letters* **104**, 141102 (2010); Title: Secondary Photons and Neutrinos from Cosmic Rays Produced by Distant Blazars

[56] Essey, W., et al., *Astrophys. J.* **731**, 51 (2011a); Title: Role of Line-of-sight Cosmic-ray Interactions in Forming the Spectra of Distant Blazars in TeV Gamma Rays and High-energy Neutrinos

[57] Essey, W., Ando, Sh., & Kusenko, A., *Astropart. Phys.* **35**, 135 - 139 (2011b); Title: Determination of intergalactic magnetic fields from gamma ray data

[58] Essey, W., & Kusenko, A., *Astropart. Phys.* **57**, 30 - 32 (2014); Title: Understanding the spectrum of a distant blazar PKS 1424 + 240 and its implications

[59] Everett, J., et al., *Astrophys. J.* **674**, 258 (2008); Title: The Milky Way's Kiloparsec-Scale Wind: A Hybrid Cosmic-Ray and Thermally Driven Outflow

[60] Everett, J., et al., *"The Role of the Disk-Halo Interaction in Galaxy Evolution: Outflow vs. Infall?"*, Ed. M.A. de Avillez; EAS Publ. **56**, 73 (2012); Title: Cosmic Ray- and Thermal-Pressure Driven Winds: Does the Milky Way Host a Kpc-Scale Outflow?

[61] Falcke, H., et al., *Astrophys. J.* **542**, 197 - 200 (2000); Title: Radio Sources in Low-Luminosity Active Galactic Nuclei. II. Very Long Baseline Interferometry Detections of Compact Radio Cores and Jets in a Sample of LINERs

[62] Fargion, D., et al., ISVHECRI 2014 - 18th International Symposium on Very High Energy Cosmic Ray Interactions, CERN, Geneva, Edited by D. Berge; A. de Roeck; M. Mangano; B. Pattison; EPJ Web of Conferences, Volume 99, id.08002 (2015); arXiv:1412.1573; The meaning of the UHECR Hot Spots: A Light Nuclei Nearby Astronomy

[63] Farrar, G.R., & Piran, T., *Phys. Rev. Letters* **84**, 3527 - 3530 (2000); Title: Violation of the Greisen-Zatsepin-Kuzmin Cutoff: A Tempest in a (Magnetic) Teapot? Why Cosmic Ray Energies above $10^{20}$ eV May Not Require New Physics

[64] Farrar, G.R., & Piran, T., eprint arXiv:1411.0704 (2014); Title: Tidal disruption jets as the source of Ultra-High Energy Cosmic Rays

[65] Fialkov, A., *Int. J. of Mod. Phys.* **D 23**, 1430017 (2014); Title: Supersonic relative velocity between dark matter and baryons: A review

[66] Fixsen, D.J., et al., *Astrophys. J.* **734**, 5 (2011); Title: ARCADE 2 Measurement of the Absolute Sky Brightness at 3-90 GHz,

[67] Frieman, J.A., Turner, M.S., & Huterer, D., *Annual Rev. of Astron. & Astrophys.* **46**, 385 - 432 (2008); Title: Dark Energy and the Accelerating Universe

[68] Gagne, J.P., et al., *Astrophys. J.* **792**, 72 (2014); Title: Spatially Resolved Spectra of the "Teacup" Active Galactic Nucleus: Tracing the History of a Dying Quasar

[69] Gaisser, T.K., Stanev, T., & Tilav, S., *Front. of Phys.* **8**, 748 (2013); Title: Cosmic ray energy spectrum from measurements of air showers

[70] Gallant, Y.A., & Achterberg, A., *Month. Not. Roy. Astr. Soc.* **305**, L6 - L10 (1999); Title: Ultra-high-energy cosmic ray acceleration by relativistic blast waves

PoS(MULTIF15)008

[71] Galli, D., & Palla, F., *Annual Rev. of Astron. & Astrophys.* **51**, 163 - 206 (2013); Title: The Dawn of Chemistry

[72] Gentile, G., et al., *Nature* **461**, 627 (2009); Title: Universality of galactic surface densities within one dark halo scale-length

[73] Gilmore, G., et al., *Astrophys. J.* **663**, 948 - 959 (2007); Title: The Observed Properties of Dark Matter on Small Spatial Scales

[74] Gilmore, G., et al., *Conf. Proc. A.S.P. Panoramic Views of Galaxy Formation and Evolution* **399**, 453 (2008); Title: What Is a Galaxy? How Cold Is Cold Dark Matter? Recent Progress in Near Field Cosmology

[75] Ginzburg, V.L., & Syrovatskii, S.I., *Astron. Zh.* **40**, 466 (1963); transl. *Sov. Astron.* **7**, 357 (1963); Title: Cosmic Rays in Metagalactic Space

[76] Gizani, N.A.B., & Leahy, J.P., *Month. Not. Roy. Astr. Soc.* **342**, 399 (2003); Title: A multiband study of Hercules A - II. Multifrequency VLA imaging

[77] Gopal-Krishna, & Wiita, P.J., *Astrophys. J. Letters* **560**, L115 - L118 (2001); Title: Was the Cosmic Web of Protogalactic Material Permeated by Lobes of Radio Galaxies During the Quasar Era?

[78] Gopal-Krishna, et al., *Astrophys. J. Letters* **720**, L155 (2010); Title: Ultra-high-energy Cosmic Rays from Centaurus A: Jet Interaction with Gaseous Shells

[79] Gregorini, L., et al., *Astron. J.* 89, **323** (1984); Title: The low-frequency spectra of a complete sample of extragalactic radio sources

[80] Greisen, K., *Phys. Rev. Letters* **16**, 748 - 750 (1966) Title: End to the Cosmic-Ray Spectrum?

[81] Hawking, S.W., *Phys. Rev. Letters* **26**, 1344 - 1346 (1971) Title: Gravitational Radiation from Colliding Black Holes

[82] Heger, A., et al., *Astrophys. J.* **591**, 288 - 300 (2003); Title: How Massive Single Stars End Their Life

[83] Hennawi, J.F., et al., *Science* **348**, 779 - 783 (2015); Title: Quasar quartet embedded in giant nebula reveals rare massive structure in distant universe

[84] Hillas, A.M., *Annual Rev. of Astron. & Astrophys.* **22**, 425 - 444 (1984); Title: The Origin of Ultra-High-Energy Cosmic Rays

[85] Hogan, C.J., & Dalcanton, J. J., *Phys. Rev.* **D 62**, 063511 (2000); Title: New dark matter physics: Clues from halo structure

[86] Holder, G.P., *Astrophys. J.* **780**, 112 (2014); Title: The Unusual Smoothness of the Extragalactic Unresolved Radio Background

[87] Kachelrieß, M., Ostapchenko, S., & Tomàs, R., *Int. J. of Mod. Phys.* **D 18**, 1591 - 1595 (2009); Title: Multi-Messenger Astronomy with Centaurus A

[88] Kapteyn, J. C., *Astron. Nachr.* **157**, 201 (1901) Title: Über die Bewegung der Nebel in der Umgebung von Nova Persei

[89] Keel, W.C., et al., *Astron. J.* **144**, 66 (2012); Title: The History and Environment of a Faded Quasar: Hubble Space Telescope Observations of Hanny's Voorwerp and IC 2497

[90] Keel, W.C., et al., *Astron. J.* **149**, 155 (2015); Title: HST Imaging of Fading AGN Candidates. I. Host-galaxy Properties and Origin of the Extended Gas

[91] Keivani, A., Farrar, G.R., & Sutherland, M., *Astropart. Phys.* **61**, 47 - 55 (2015); Title: Magnetic deflections of ultra-high energy cosmic rays from Centaurus A

[92] Kennicutt, R.C., Jr., *Annual Rev. of Astron. & Astrophys.* **36**, 189 - 232 (1998); Title: Star Formation in Galaxies Along the Hubble Sequence

[93] Kino, M., et al., *Astrophys. J.* **803**, 30 (2015); Title: Magnetization Degree at the Jet Base of M87 Derived from the Event Horizon Telescope Data: Testing the Magnetically Driven Jet Paradigm

[94] Klioner, S. A., *EAS Publ. Ser.*, **67-68**, 49 - 55 (2014); Title: Gaia Astrometry and Fundamental Physics

[95] Kneiske, T.M., & Dole, H., *Astron. & Astroph.* **515**, A19 (2010); Title: A lower-limit flux for the extragalactic background light

[96] Kogut, A., et al., *Astrophys. J. Suppl.* **148**, 161 - 173 (2003); Title: First-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Temperature-Polarization Correlation

[97] Kogut, A., et al., *Astrophys. J.* **734**, 4 (2011); Title: ARCADE 2 Observations of Galactic Radio Emission

[98] Kollmeier, J.A., et al., *Astrophys. J. Letters* **789**, L32 (2014); Title: The Photon Underproduction Crisis

[99] Koposov, S., et al., *Astrophys. J.* **686**, 279 - 291 (2008); Title: The Luminosity Function of the Milky Way Satellites

[100] Kormendy, J., et al. *Astrophys. J.* **723**, 54 - 80 (2010); Title: Bulgeless Giant Galaxies Challenge Our Picture of Galaxy Formation by Hierarchical Clustering

[101] Kormendy, J., Bender, R., & Cornell, M.E., *Nature* **469**, 374 - 376 (2011a); Title: Supermassive black holes do not correlate with galaxy disks or pseudobulges

[102] Kormendy, J., & Bender, R., *Nature* **469**, 377 - 380 (2011b); Title: Supermassive black holes do not correlate with dark matter haloes of galaxies

[103] Kotera, K., Olinto, A.V., *Annual Rev. of Astron. & Astrophys.* **49**, 119-153 (2011); Title: The Astrophysics of Ultrahigh-Energy Cosmic Rays

[104] Krause, O., et al., *Science* **308**, 1604 - 1606 (2005); Title: Infrared Echoes near the Supernova Remnant Cassiopeia A

[105] Krauß, F., et al., *Astron. & Astroph.* **566**, L7 (2014); Title: TANAMI blazars in the IceCube PeV-neutrino fields

[106] Kronberg, P.P., & Biermann, P.L., *Astrophys. J.* **243**, 89 - 91, 93 - 96 (1981); Title: The radio structure of the nuclear region of NGC 2146

[107] Kronberg, P.P., Biermann, P.L., & Schwab, F.R., *Astrophys. J.* **291**, 693 - 707 (1985); Title: The nucleus of M82 at radio and X-ray bands - Discovery of a new radio population of supernova candidates

[108] Kronberg, P.P., et al., *Astrophys. J.* **659**, 267 - 274 (2007); Title: Discovery of New Faint Radio Emission on 8 deg to 3 arcmin Scales in the Coma Field, and Some Galactic and Extragalactic Implications

[109] Kronberg, P.P., et al., *Astrophys. J.* **676**, 70 - 79 (2008); Title: A Global Probe of Cosmic Magnetic Fields to High Redshifts

[110] Kroupa, P., *Can. J. Phys.* **93**, 169 - 202 (2015); Title: Galaxies as simple dynamical systems: observational data disfavor dark matter and stochastic star formation

[111] Lagache, G., Puget, J.-L., & Dole, H., *Annual Rev. of Astron. & Astrophys.* **43**, 727 - 768 (2005); Title: Dusty Infrared Galaxies: Sources of the Cosmic Infrared Background

[112] Linsley, J., *Phys. Rev. Letters* **10**, 146 - 148 (1963); Title: Evidence for a Primary Cosmic-Ray Particle with Energy $10^{20}$ eV

[113] Lucy, L.B., & Solomon, P.M., *Astrophys. J.* **159**, 879 (1970); Title: Mass Loss by Hot Stars

[114] Mannheim, K., et al., *Astron. & Astroph.* **315**, 77 - 85 (1996); Title: Beacons at the gamma ray horizon

[115] Mignard, F.; Klioner, S., *Astron. & Astroph.* **547**, A59 (2012); Title: Analysis of astrometric catalogues with vector spherical harmonics

[116] Milgrom, M., eprint arXiv:1404.7661 (2014): in special issue of the Canadian Journal of Physics dedicated to MOND. Title: MOND theory

[117] Mirabel, I.F., et al., *Astron. & Astroph.* **528**, A149 (2011); Title: Stellar black holes at the dawn of the universe

[118] Müller, C., et al., eprint arXiv:1502.02879 (2015); Title: Consequences of a possible jet-star interaction in the inner central parsec of Centaurus A

[119] Munyaneza, F., & Biermann, P.L., *Astron. & Astroph.* **436**, 805 (2005); Title: Fast growth of supermassive black holes in galaxies

[120] Munyaneza, F., & Biermann, P.L., *Astron. & Astroph. Letters* **458**, L9 (2006); Title: Degenerate sterile neutrino dark matter in the cores of galaxies

[121] Nagar, N.M., et al., *Astrophys. J.* **542**, 186 - 196 (2000); Title: Radio Sources in Low-Luminosity Active Galactic Nuclei. I. VLA Detections of Compact, Flat-Spectrum Cores

[122] Nagar, N.M., Wilson, A.S., & Falcke, H., *Astrophys. J.* **559**, L87 - L90 (2001); Title: Evidence for Jet Domination of the Nuclear Radio Emission in Low-Luminosity Active Galactic Nuclei

[123] Nagar, N.M., et al., *Astron. & Astroph.* **392** 53 - 82 (2002a); Title: Radio sources in low-luminosity active galactic nuclei. III. "AGNs" in a distance-limited sample of "LLAGNs"

[124] Nagar, N.M., et al., *New Astron. Rev.* **46**, 225 - 229 (2002b); Title: 'Radio-loud' low luminosity AGN

[125] Nagar, N.M., Falcke, H., & Wilson, A.S., *Astron. & Astroph.* **435**, 521 - 543 (2005); Title: Radio sources in low-luminosity active galactic nuclei. IV. Radio luminosity function, importance of jet power, and radio properties of the complete Palomar sample

[126] Nellen, L., Mannheim, K., & Biermann, P.L., *Phys. Rev.* **D 47**, 5270 - 5274 (1993); Title: Neutrino production through hadronic cascades in AGN accretion disks

[127] Neronov, A., et al., *Astrophys. J. Letters* **719**, L130 - L133 (2010); Title: Degree-scale GeV "Jets" from Active and Dead TeV Blazars

[128] O'Leary, R.M., & McQuinn, M., *Astrophys. J.* **760**, 4 (2012); Title: The Formation of the First Cosmic Structures and the Physics of the z $\sim$ 20 Universe

[129] Paduroiu, S., Revaz, Y., & Pfenniger, D., eprint arXiv:1506.03789 (2015); Title: Structure formation in warm dark matter cosmologies: Top-Bottom Upside-Down

[130] Rachen, J.P., Stanev, T., & Biermann, P.L., *Astron. & Astroph.* **273**, 377 (1993); Title: Extragalactic ultra-high energy cosmic rays. II. Comparison with experimental data

[131] Rachen, J.P., & Mészáros, P., *Phys. Rev.* **D 58**, 123005 (1998); Title: Photohadronic neutrinos from transients in astrophysical sources

[132] Raue, M., Kneiske, T., & Mazin, D., *Astron. & Astroph.* **498**, 25 - 35 (2009); Title: First stars and the extragalactic background light: how recent gamma-ray observations constrain the early universe

[133] Rossa, J., & Dettmar, R.-J., *Astron. & Astroph.* **406**, 493 (2003); Title: An Halpha survey aiming at the detection of extraplanar diffuse ionized gas in halos of edge-on spiral galaxies. I. How common are gaseous halos among non-starburst galaxies?

[134] Ryu, D., et al., *Science* **320**, 909 (2008); Title: Turbulence and Magnetic Fields in the Large-Scale Structure of the Universe

[135] Ryu, D., Das, S., & Kang, H., *Astrophys. J.* **710**, 1422 - 1431 (2010); Title: Intergalactic Magnetic Field and Arrival Direction of Ultra-High-Energy Protons

[136] Salucci, P., al., et *Month. Not. Roy. Astr. Soc.* **420**, 2034 (2012); Title: Dwarf spheroidal galaxy kinematics and spiral galaxy scaling laws

[137] Sanders, R. H., *Astrophys. J.* **162**, 791 (1970); Title: The Effects of Stellar Collisions in Dense Stellar Systems

[138] Sarkar, K., et al., *Month. Not. Roy. Astr. Soc.* **448**, 328 (2015); Title: Long way to go: how outflows from large galaxies propagate through the hot halo gas

[139] Schaefer, B.E., *Astrophys. J. Letters* **323**, L51 - L54 (1987); Title: Light echoes - Type II supernovae

[140] Seiffert, M., et al., *Astrophys. J.* **734**, 6 (2011); Title: Interpretation of the ARCADE 2 Absolute Sky Brightness Measurement,

[141] Silk, J., & Takahashi, T., *Astrophys. J.* **229**, 242 - 256 (1979); Title: A statistical model for the initial stellar mass function

[142] Simpson, J.M., et al., *Astrophys. J.* **799**, 81 (2015); Title: The SCUBA-2 Cosmology Legacy Survey: ALMA Resolves the Rest-frame Far-infrared Emission of Sub-millimeter Galaxies

[143] Smochulowski, M., *Z. f. Physik* **17**, 557 (1916); Title: ...

[144] Spitzer, L., Jr., *Astrophys. J. Letters* **158**, L139 (1969); Title: Equipartition and the Formation of Compact Nuclei in Spherical Stellar Systems

[145] Strigari, L.E., et al., *Nature* **454**, 1096 (2008); Title: A common mass scale for satellite galaxies of the Milky Way

[146] Su, M., Slatyer, T.R., & Finkbeiner, D.P., *Astrophys. J.* **724**, 1044 - 1082 (2010); Title: Giant Gamma-ray Bubbles from Fermi-LAT: Active Galactic Nucleus Activity or Bipolar Galactic Wind?

[147] Tabatabaei, F. S., Beck, R., & Berkhuijsen, E., *Highlights of Astron.* **15**, 417 (2010); Title: The radio-infrared correlation in galaxies

[148] Tabatabaei, F.S., et al., in *The Spectral Energy Distribution of Galaxies*, IAU Sympos. **284**, 400 - 403 (2012) Title: The resolved radio-FIR correlation in nearby galaxies with Herschel and Spitzer

[149] Tabatabaei, F. S., et al., *Astron. & Astroph.* **557**, A129 (2013); Title: Multi-scale radio-infrared correlations in M 31 and M 33: The role of magnetic fields and star formation

[150] Taylor, S. R., et al., EPTA-Coll., *Phys. Rev. Letters* **115**, 041101 (2015); Title: Limits on Anisotropy in the Nanohertz Stochastic Gravitational Wave Background

[151] Todero Peixoto, C.J., et al., *J.C.A.P.*, (2015) as: JCAP07(2015)042; eprint arXiv:1502.00305; Title: Cosmic rays: the spectrum and chemical composition from $10^{10}$ to $10^{20}$ eV

[152] Tseliakhovich, D., & Hirata, Ch., *Phys. Rev.* **D 82**, 083520 (2010); Title: Relative velocity of dark matter and baryonic fluids and the formation of the first structures

[153] Uhlig, M., et al., *Month. Not. Roy. Astr. Soc.* **423**, 2374 (2012); Title: Galactic winds driven by cosmic ray streaming

[154] Unger, M., Farrar, G.R., & Anchordoqui, L.A., *Phys. Rev.* **D 92**, 123001 (2015); arXiv:1505.02153 ; Title: Origin of the ankle in the ultra-high energy cosmic ray spectrum and of the extragalactic protons below it

[155] de Vega, H.J., Salucci, P., & Sanchez, N.G., *Month. Not. Roy. Astr. Soc.* **442**, 2717 (2014); Title: Observational rotation curves and density profiles versus the Thomas-Fermi galaxy structure theory

[156] Visbal, E., et al., *Nature* **487**, 70 - 73 (2012); Title: The signature of the first stars in atomic hydrogen at redshift 20

[157] Völk, H. J., *Astron. & Astroph.* **218**, 67 - 70 (1989); Title: The correlation between radio and far-infrared emission for disk galaxies - A calorimeter theory

[158] Walg, S., et al., *Month. Not. Roy. Astr. Soc.* **439**, 3969 - 3985 (2014); Title: Relativistic AGN jets - II. Jet properties and mixing effects for episodic jet activity

[159] Wykes, S., et al., *Astron. & Astroph.* **558**, A19 (2013); Title: Mass entrainment and turbulence-driven acceleration of ultra-high energy cosmic rays in Centaurus A

[160] Wykes, S., et al., *Month. Not. Roy. Astr. Soc.* **442**, 2867 - 2882 (2014); Title: Filaments in the southern giant lobe of Centaurus A: constraints on nature and origin from modelling and GMRT observations

[161] Wykes, S., et al., *Month. Not. Roy. Astr. Soc.* **447**, 1001 - 1013 (2015); Title: Internal entrainment and the origin of jet-related broad-band emission in Centaurus A

[162] Yang, Y., et al., *Month. Not. Roy. Astr. Soc.* **442**, 2419 (2014); Title: Reproducing properties of MW dSphs as descendants of DM-free TDGs

[163] Yüksel, H., et al., *Astrophys. J.* **758**, 16 (2012); Title: The Centaurus A Ultrahigh-energy Cosmic-Ray Excess and the Local Extragalactic Magnetic Field

[164] Yungelson, L.R., et al., *Astron. & Astroph.* **477**, 223 - 237 (2008); Title: On the evolution and fate of super-massive stars

[165] Zatsepin, G.T., & Kuz'min, V.A., *Zh. Exp. Th. Fiz. Pis'ma* **4**, 114 (1966); transl. *J. Exp. & and Theor. Phys. Lett.* **4**, 78 (1966); Title: Upper Limit of the Spectrum of Cosmic Rays

[166] Zdziarski, A.A., & Böttcher, M., *Month. Not. Roy. Astr. Soc.* **450**, L21 - L25 (2015); Title: Hadronic models of blazars require a change of the accretion paradigm